

Exudation of Mesotrione from Potato Roots Injures Neighboring Plants

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Mesotrione is an effective herbicide for volunteer potato control but is not selective in several crops, including onion and carrot. Studies were conducted in 2006 to evaluate the effectiveness of wiper-applied mesotrione for control of volunteer potato in a potato crop. Surprisingly, nontreated potatoes growing adjacent to mesotrione-treated plants exhibited bleaching symptoms resembling mesotrione injury. Additional field trials confirmed injury to nontreated plants growing within 26 cm of potatoes treated with mesotrione applied with a wiper at 0.25, 0.5, and 1% (v/v) solutions. Greenhouse bioassays confirmed that mesotrione applied to potato leaves moved down through the plant and was exuded into perlite potting medium in sufficient quantities to injure potato plants that were exposed to the leachate from the perlite pots. In tracer studies, 52% of ^{14}C -labeled mesotrione applied to potato leaves was absorbed into the potato plant by 15 d and 15% of the absorbed ^{14}C -mesotrione was exuded into the soil and soil leachate. Mesotrione applied to potato by the wick application method has potential to injure neighboring susceptible plants from root uptake of exuded mesotrione.

Nomenclature: Mesotrione; carrot, *Daucus carota* L.; onion, *Allium cepa* L.; potato, *Solanum tuberosum* L.

Key words: Excretion, herbicide, root exudate, root exudation.

Mesotrione is an effective herbicide for control of volunteer potato and other weeds in field corn (*Zea mays* L.) and sweet corn (Boydston 2001; Boydston and Williams 2005; Johnson et al. 2002). Volunteer potato infests many crops when winter soil temperatures fail to fall below the $-1.5\text{ }^{\circ}\text{C}$ required to kill tubers left in the soil following potato harvest (Boydston et al. 2006). Mesotrione is a synthetic analogue of the allelochemical leptospermane, which is exuded by the roots of the Skeels crimson bottlebrush plant (*Callistemon citrinus* Curtis) (Cornes 2005; Mitchell et al. 2001). Although mesotrione selectively controls volunteer potato and other weeds in corn, it severely injures several other common-rotation crops, such as carrot and onion, which must often be hand-weeded to control volunteer potatoes to prevent yield loss (Williams and Boydston 2005; Williams et al. 2004). Selective application of mesotrione to potato foliage may allow for control of volunteer potato in crops that would otherwise be injured by a broadcast application.

In field trials conducted in 2006, mesotrione¹ was applied in a 1% (v/v) aqueous solution with a wiper applicator to individual volunteer potato plants in a field planted to potato. Surprisingly, nontreated potato plants growing adjacent to treated volunteer potatoes began to show bleaching symptoms typical of mesotrione, and many plants eventually died. Apparently, the herbicide or a metabolite had moved from the treated plants to the adjacent nontreated plants. Given the relatively low vapor pressure of mesotrione and its mobility in both phloem and xylem (WSSA 2007), movement via root exudation was suspected. Two known metabolites of mesotrione: 4-methylsulfonyl-2-nitrobenzoic acid 2 (MNBA) and 2-amino-4-methylsulfonyl benzoic acid 3 (AMBA) are not herbicidal (Armel et al. 2005).

Root exudation of foliar-applied herbicides has been reported previously (Dinelli et al. 2007; Linder et al. 1964; Reid and Hurtt 1970). Up to 25% of 2,4-D applied to leaves of jimsonweed (*Datura stramonium* L.) was exuded from the roots in a 6-wk period (Fites et al. 1964). Nightflowering catchfly (*Silene noctiflora* L.) exuded 2,4-D from roots in a similar fashion (Neidermyer and Nalewaja 1969). Biologically

measurable amounts of ^{14}C -glyphosate were exuded from roots of quackgrass [*Elymus repens* (L.) Gould] at 8 d after foliar application (Coupland and Caseley 1979). Similarly wheat (*Triticum aestivum* L.) plants exuded ^{14}C -glyphosate from roots into soil, which was taken up by neighboring corn seedlings (Rodrigues et al. 1982). Imazapyr applied to the foliage of grand eucalyptus (*Eucalyptus grandis* W. Hill ex Maid.) injured neighboring, nontreated bioassay plants (Silva et al. 2004), and imazapyr applied to the whorl of corn plants moved systemically out of roots killing witchweed (*Striga* Lour. spp.) (Kanampiu et al. 2002).

The objectives of the current studies were (1) to determine whether foliar-applied mesotrione is exuded from the roots of treated potato plants in sufficient quantities to injure adjacent plants through root uptake; and (2) to quantify the amount of foliar-applied ^{14}C -mesotrione exuded from the roots of treated potato plants.

Materials and Methods

Quantifying Mesotrione Movement in Field Trials. Two field trials were conducted in 2006 in potato grown under sprinkler irrigation near Prosser, WA, on a Warden sandy-loam soil, at pH 7.1, and containing 1% organic matter. Potato var. 'Russet Burbank' whole-seed tubers, averaging 75 g, were planted 20 cm deep by hand on June 28, 2006, and July 20, 2006. Individual plots consisted of a single 2-m-long row of potatoes with a plant-to-plant spacing of 10, 20, or 30 cm. Individual plots contained 7, 11, or 19 plants for the 30-, 20-, and 10-cm plant spacings, respectively. Rows were spaced 90 cm apart. Treatments of plant spacing and herbicide concentration were arranged in a three by three factorial replicated four times in a randomized complete-block design. Plots were hand-weeded to control annual weeds.

Mesotrione¹ was applied with a sponge wetted with 0.25, 0.5, or 1% (v/v) aqueous solution. Mesotrione was applied on July 31, 2006, and August 16, 2006, in trials 1 and 2, respectively, when potatoes were 15 to 20 cm tall. One plant near the center of each plot was treated by wiping the appropriate mesotrione solution on the three newest-emerging leaves in the center of the plant using a sponge. Treated plants were isolated from neighboring plants with fiber cones to ensure no foliar transfer of mesotrione from plant to plant.

DOI: 10.1614/WS-08-064.1

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Figure 1. Experimental setup for collection of leachate from mesotrione-treated plants (upper) and application to soil of nontreated plants (lower).

Mesotrione bleaching symptoms on potato were recorded on the treated and adjacent potato plants at 2 and 4 wk after treatment (WAT). The distances from the center of the treated plant to the furthest shoot showing bleaching symptoms within the row on both sides of the treated plant were measured and recorded at 4 WAT. Severity of bleaching symptoms on treated plants was recorded at 4 WAT on a scale of 0 (no injury symptoms) to 100 (totally bleached).

Quantifying Mesotrione Movement in Greenhouse Trials.

Trials were conducted in 2007 to determine whether leachate collected from containers of mesotrione-treated plants would injure potato plants when applied to perlite growing medium. Single potatoes, var. Ranger Russet, whole-seed tuber, averaging 70 g, were planted in 2.8-L containers filled with perlite. Perlite was kept moist, and once potatoes began to emerge, plants were watered daily with 0.3-ml of fertilizer² per liter of water. When plants reached 13 cm, a 1% (v/v) aqueous solution of mesotrione¹ was applied with a sponge to the newest-emerged three leaves in the center of five plants. Five nontreated plants were included as controls, and 10 additional nontreated plants were maintained to receive leachate from treated and control plants. All plants were maintained in a greenhouse at 28/18 C \pm 3 day/night temperature. Day length was extended to 14 h with sodium vapor lamps delivering 650 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD). Beginning on the day of treatment, and continuing for 20 d, treated and nontreated control plants were watered daily with an average of 250 ml of fertilizer solution, which yielded approximately 120 ml of leachate container⁻¹ d⁻¹. Pots were placed over funnels to collect the leachate into a beaker (Figure 1). The volume of leachate was measured and then carefully poured onto the perlite surface of pots containing nontreated potato plants.

Plants were observed daily to record initial appearance of mesotrione symptoms. At 20 d after treatment (DAT), potato injury was rated on a scale of 0 (no injury) to 100 (totally bleached), and the number and weight of new potato tubers produced was determined.

Quantifying Mesotrione Absorption and Exudation. Single, Ranger Russet, whole-seed tuber potatoes, averaging 70 g, were planted 5 cm deep in 700 g of sand in 1.5-L containers. Pots containing a potato plant were placed in a secondary container to collect leachate. Pots were watered as needed to keep the sand moist until potato shoot emergence, when containers were watered and fertilized daily with a commercial fertilizer² as previously described. Two weeks after emergence, plants were thinned to 2 shoots pot⁻¹. Plants were grown in the greenhouse at 26/24 \pm 3 C day/night temperatures. Day length was extended to 16 h with supplemental mercury lamps delivering 80 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD.

At the six-leaf stage, 40, 1- μl droplets, containing a total of 6.88 kBq mesotrione (phenyl -U-¹⁴C; specific activity 0.165 TBq g⁻¹), were applied uniformly with a microsyringe across the upper surface of the second- and third-youngest leaf of each shoot. Nonlabeled mesotrione was added to obtain a solution with the equivalent concentration of active ingredient of a spray solution resulting from mixing the field use rate (0.1 kg ai ha⁻¹) in 187 L ha⁻¹ water. Mesotrione was applied with 1% (v/v) crop oil concentrate. After mesotrione treatment, plants received 200 ml of fertilizer² solution daily, and leachate was collected every 3 d until harvest. Leachate was evaporated³ at 35 C until less than 0.3 ml of solution was left, then radioactivity was quantified by liquid scintillation spectrometry (LSS).⁴

Plants were harvested at 15 DAT and separated into treated leaf, other foliage, root, and seed tuber. Treated leaves were rinsed with 80 ml of a 75% methanol solution to remove nonabsorbed mesotrione. Plant sections were dried at 40 C and then oxidized using a biological oxidizer.⁵ Trapped ¹⁴CO₂ was quantified using LSS. In addition, sand from each pot was dried for 48 h under a hood, the dried sand was mixed and weighed, and a 0.5-g subsample was oxidized to determine radioactivity present. Absorption was calculated by comparing radioactivity recovered in the entire plant to the sum of the radioactivity in the plant plus radioactivity in the leaf rinsate, soil leachate, and sand. Percentage of root exudation was computed by dividing the radioactivity recovered in the soil and leachate by the radioactivity recovered in the plant plus the radioactivity in the soil and leachate. Treatments were replicated three times, and the study was repeated.

Statistical Analysis. ANOVA was performed using PROC GLM procedure in SAS (SAS 2000). ANOVA did not indicate a trial effect or significant trial by treatment interactions, so data were combined across trials, and treatment means were separated by Fisher's Protected LSD procedure at P = 0.05.

Results and Discussion

Quantifying Mesotrione Movement in Field Trials. Bleaching symptoms began to appear on treated potato plants approximately 6 DAT. By 2 WAT, bleaching symptoms were readily visible on plants adjacent to treated plants, confirming our initial observations that mesotrione or an unknown active metabolite was moving from treated portions of the potato into roots or shoots of adjacent, nontreated plants. Mesotrione concentration (0.25, 0.5, and 1%) had no significant effect on any of the measured parameters, and there was no significant mesotrione concentration by the potato spacing interaction,

Table 1. Amount of potato injury, distance mesotrione-injured plants were from treated plant, and number of adjacent plants injured at 4 wk after treatment in 2006 near Prosser, WA.^a

Plant spacing	Injury to treated plant ^b	Distance of injured plant from treated plant ^c	Adjacent plants injured ^d
cm	%	cm	No.
10	54 b	23 a	2.4 a
20	68 a	23 a	1.3 b
30	71 a	26 a	0.9 c

^a Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at a P = 0.05 level.

^b Injury rated on a scale of 0 (no symptoms) to 100 (dead).

^c Distance from the center of the treated plant to the furthest stem of the adjacent nontreated plant that exhibited bleaching symptoms. Data are averaged over both sides of the treated plant within the row.

^d Number of adjacent plants on either side of treated plant exhibiting bleaching symptoms.

so the data presented are means over all mesotrione concentrations. Plant spacing significantly affected the amount of injury to the treated plant and the number of neighboring plants that were injured. Four weeks after treatment, potatoes spaced at 20 and 30 cm were injured 68 and 71% compared with only 54% at the 10 cm spacing (Table 1). The reduced injury observed on treated plants spaced at 10 cm may be due, in part, to greater uptake of mesotrione and limited metabolism and retention by neighboring plants, making them less available for repeated uptake by the roots of the treated plants. In addition, less injury to treated plants spaced at 10 cm may be due to increased water use by surrounding plants, resulting in decreased soil moisture and increased root exudation of mesotrione from treated plants.

Injury symptoms on adjacent plants were not evident beyond 27 cm from the treated plant (Table 1). Averaged over all mesotrione concentrations, injury to plants adjacent to treated plants was limited to 0.9, 1.3, and 2.4 plants on either side of the treated plant at the 30, 20, and 10 cm spacing, respectively (Table 1). Roots or underground shoots of nontreated adjacent plants need to be in relatively close proximity to the treated plant to absorb mesotrione exuded by the treated plants. At the close plant spacing of 10 cm, more neighboring plants are likely to have roots or underground shoots in the region where mesotrione was exuded from the treated plant than at the 20 and 30 cm plant spacings.

Table 2. Potato injury and tuber production on plants 20 d after application of mesotrione with a wiper or from application of leachate collected from mesotrione-treated plants in greenhouse trials in 2007 near Prosser, WA.^a

Treatment	Injury ^b	Tuber number	Tuber weight
	%	No. plant ⁻¹	g plant ⁻¹
Nontreated control	0 b	2.6 a	6.0 a
Plants receiving leachate from nontreated control	0 b	2.8 a	6.9 a
Mesotrione applied by wiper	72 a	0.2 b	0.2 b
Plants receiving leachate from mesotrione-treated plants	60 a	0.1 b	0.1 b

^a All data were collected at 20 d after treatment.

^b Means presented are averaged over two trials, and means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at a P = 0.05 level.

Quantifying Mesotrione Movement in Greenhouse Trials.

Bleaching symptoms appeared on treated potato plants at 3 DAT. By 10 DAT bleaching symptoms began to appear on plants receiving leachate from treated plants. Symptoms occurred first in the youngest emerging leaves in the center of the plant for both the treated plants and plants receiving leachate from treated plants. At 20 DAT, mesotrione-treated plants had 72% injury, whereas plants receiving leachate from containers with treated plants were injured 60% (Table 2). No symptoms developed in nontreated potato plants or in plants receiving leachate from nontreated plants (Table 2). Mesotrione-treated plants and plants receiving leachate from mesotrione-treated plants produced few or no tubers by 20 DAT, whereas nontreated control plants and plants receiving leachate from nontreated controls produced 2.6 and 2.8 tubers plant⁻¹, weighing 6 and 7 g tuber⁻¹, respectively (Table 2).

This provides further evidence that mesotrione or an unknown active metabolite is exuded from treated potato plant roots and is readily taken up by roots or underground shoots of nontreated plants. This also demonstrates that it is not necessary for roots of treated and nontreated plants to be in direct contact for plant-to-plant transfer of mesotrione to occur. Mesotrione is exuded by the roots of treated plants into the soil solution and available for uptake by neighboring plant roots or underground shoots.

Quantifying Mesotrione Absorption and Exudation. About 33% of the applied ¹⁴C-mesotrione remained in the treated leaves, and 25 to 30% of the absorbed ¹⁴C-mesotrione was recovered from the roots or root exudates at 15 DAT (data not shown). At 15 DAT, potato plants absorbed 52 ± 5% (SE) of applied ¹⁴C-mesotrione, and 15 ± 4.5% of the absorbed ¹⁴C-mesotrione was exuded from the plant. Therefore, 7.8% of the applied mesotrione was exuded from the potato roots into the surrounding soil and available for plant uptake. In a previous study, only 1 to 2% of foliar-applied ¹⁴C-mesotrione was translocated to roots of Canada thistle [*Cirsium arvense* (L.) Scop.] at 72 h after treatment (Armel et al. 2005).

These studies demonstrate that mesotrione can move from treated portions of potatoes into neighboring potatoes. Potatoes are extremely susceptible to low doses of mesotrione and exudation of mesotrione from potato roots was great enough to injure and sometimes kill neighboring plants. Root exudation of wiper-applied mesotrione by potato may limit the usefulness and further development of wiper applications of mesotrione in susceptible crops.

Sources of Materials

¹ Callisto, containing* 0.5 kg mesotrione L⁻¹, Syngenta Crop Protection, Greensboro, NC 27419.

² Miracle Grow (15–30–15), Scotts, 14111 Scottslawn Road, Marysville, OH 43041.

³ CentriVap, Labconco, 8811 Prospect, Kansas City, MO 64132.

⁴ Tricarb 2100TR liquid scintillation analyzer, Packard Instrument Co., 800 Research Parkway, Meriden, CT 06450.

⁵ R. J. Harvey biological oxidizer, Model OX-600, R. J. Harvey Instrument Co., 123 Patterson Street, Hillsdale, NJ 07642.

Acknowledgments

The authors acknowledge the technical assistance of Treva Anderson and thank Syngenta Crop Protection for supplying ^{14}C -mesotrione.

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Received April 2, 2008, and approved July 22, 2008.